"TECHNICAL AND INVESTIGATIVE SUPPORT FOR HIGH DENSITY DIGITAL SATELLITE RECORDING SYSTEMS"

Interim Report E6514 and E6519

Period Covering Jan. - Feb. 1982

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1. INTRODUCTION

This progress report described methods and results of magnetic tape. The results add to or replace those presented in the November - December, 1981 progress report. The report sections describe test method improvements, mention possible sources of error in some tests, and discuss plans to investigate test difficulties and improve methods of data analysis.

The previous results of 3M Types 890 and 973 have been deleted from this report. Availability of tape in suitable widths continues to obstruct standardized methods on tests where width is an important parameter. These tests include flexibility, coefficients of friction, and abrasivity. The Fuji Beridox tape samples evaluated in this report were obtained from a 1/2 inch video cassette.

2. PHYSICAL PROPERTIES

The results of physical property testing have been separated into tables relating to bulk properties (Table 1) and oxide surface properties (Table 2) in order to facilitate correlation of the test results. The text describes test method improvements for abrasion resistance, abrasity, and coefficients of friction. Additional friction test improvement is anticipated prior to obtaining suitable sample widths of all tape types. Results of lubricant content tests, ion microprobe surface analysis, and additional thickness measurements have been added to this report. Plans for the next reporting period include scanning electron micrographs of oxide surfaces.

2.1 Abrasion Resistance

This test procedure has been refined and modified since the previous report with the intent of increased objectivity and more easily interpreted results. Useable raw data has been obtained, and methods of treating the raw data are discussed below.

2.1.1 Procedure

A supply of new 0.125 inch diameter Grade 25 chrome steel balls was obtained. These balls have a Rockwell C scale hardness specification of 62-66 and a roundness tolerance of 25 microinches.

Prior to use, shipping lubricant and contaminants are removed from the balls with benzene. Skin contact is prevented during mounting of the balls in the test fixture and during tape preperation and mounting. A new ball is employed for each test.

Prior to mounting the virgin tape samples, a small part of the back coating is removed with methyl-ethyl-ketone (MEK) and cotton swabs. Contact between the MEK and the oxide coating is avoided. Abrasion during back

coating removal is minimized by preparation without motion on a clean polyester sheet.

A 0.227 Newton (23.1 gram) normal force is applied to the tape through the steel ball as it is dragged back and forth across the tape along a 2.67 inch path. The ball passes are counted until a tungsten lamp behind the sample is visable through the clear polyester base material of the sample. Multiple samples of each tape type are tested, the minimum number of passes is noted, and the mean and standard deviation of the passes is calculated. For highly abrasion resistant tape types (above 500 passes), the wear is monitored periodically, and the number of passes between the last unworn observation and the first worn observation is averaged.

2.1.2 Results

The first column of Table 1 presents the raw data of abrasion resistance obtained with the revised procedure. The results will be normalized and corrected for oxide coating effects pending consideration of nonlinear effects caused by the test method. The most obvious nonlinear effect is the increased contact surface between the ball and the oxide if the ball wears a groove into the tape before it wears through the oxide. This would decrease the pressure on the oxide and could cause the number of passes to increase as the square of the relative abrasion resistance.

The effect of the surface finish on the steel balls is under consideration. Optical microscope observations of new balls at 400x reveal a surface finish much smoother than the worn ball surface following a large number of passes on an abrasion resistant tape type. Additional surface finish characterization of the ball surfaces including interference microscopy are planned.

2.1.3 Conclusions

The results for Ampex Type 797 indicate abrasion resistance much less than the previous test series as compared to other types in both test series.

Table 1: Bulk Physical Properties

Tape Manufacturer and Type (Lot) / Test	Abrasion Resistance (Ball Wear Test) Trials	Passes Mean	Passes σ	Passes Min	Binder Strength Observation, Ease of Removal with MEK	Thickness (mil) Oxide	Mylar	Back Coating	Total	Flexibility (degrees)
Ampex 466 (5166041921)	4	1400	303	1010	Easy	0.20 0.21	0.88 0.91	0.04 0.06	1.13 1.17	62°
Ampex 721 (11Q024182)	6	60	18	32	Difficult	0.19 0.21	0.88 0.91	0.05 0.06	1.14 1.17	67°
Ampex 797 (76142, 164485221-4, Lot A-1)	7	4	2	2	Very Easy	0.15	0.92	0.03	1.11	55°
Fuji Beridox (PFD 018)	6	119	39	75	Very Difficult	0.17	0.58	none	0.75	---
3M 5198 (51575-1-01-58)	3	1900	731	918	Difficult	0.20	0.76	0.08	1.04	---

The Ampex Type 797 sample employed in the previous series was used with a somewhat uncertain history.

Based on the current test results, the abrasion resistance of the subject tapes falls into three catagories: high resistant Ampex Type 466 and 3M Type 5198, moderately resistant Ampex Type 721 and Fuji Beridox, and nonresistant Ampex Type 797. The vast difference in test results between catagories suggests the need for theoretical consideration, life testing, or some other investigation with the aim of determining the meaningfulness of a nonlinear scale rather than the linear absolute number of passes scale of Table 1.

2.2 Binder Strength

The strength of the oxide binder system was observed subjectively during binder removal with methyl ethyl ketone (MEK) for thickness measurements. The observations are listed in the second column of Table 1. The observations indicate a loose correlation with abrasion resistance.

2.3 Tape Thickness

Tape thickness is measured during sample preperation for B-H measurements. The possible effects of solvents on the tape mylar was questioned during the following procedure. Therefore, mylar samples were re-exposed to solvents for one hour periods after the initial short preperation exposure time and thickness measurement. The long re-exposure did not change the measured mylar thickness, indicating that the short exposures do not cause errors due to mylar dissolving, swelling, or softening.

2.3.1 Procedure

Ten to sixteen layers of tape were measured with a micrometer and the results were divided by the number of layers measured. The measurements were made on the total thickness of the tape, on the tape with the back

coating removed by acetone, tricloroethylene or MEK, and cotton swabs, or Kimwipes, and on the mylar base alone with both the back coating and the magnetic oxide coating removed. The back coating and oxide thicknesses were determined by subtracting the sequential measurements.

The micrometer must be accurately zeroed and must have a slip mechanism which provides a low and repeatable measurement pressure. The micrometer may have a 0.1 mil vernier scale or, 0.1 mil resolution can be observed between 1.0 mil divisions if a vernier scale is not available . Several measurements or a single 16 layer sample should not vary by more than $\pm$0.2 mil, and the median value of those measurements can be recorded.

2.3.2 Results

Tape thickness is listed in the third column of Table 1. Differences were noted between thickness measurements of the current and previous reporting period for tape types measured during both periods. The method produces average measurements for tape sections less than three feet long, and variations might be expected over longer tape lengths. Therefore, maximum and minimum thickness values are included in the table. The precision of the measurement technique approaches $\pm$10 microinches ($\pm$0.01 mil), and the variations noted to date do not significantly exceed that level of precision.

2.4 Flexibility

2.4.1 Procedure

The relative flexibilities of the magnetic tapes were measured by the method specified in "Magnetic Head/Tape Interface Study for Satellite Tape Recorders, Technical Report, Volume I" prepared during IITRI Project No.

E6134 and dated February, 1971. The test fixture includes a horizontal clamping surface, a coordinate position of the free end of the tape, and a swing-away support which maintains the tape sample horizontally during mounting and allows the sample to bend freely for the measurement. The angle of curvature (deflection from the horizontal) was measured for the line extending between the clamping point and the free end of the tape sample. All tapes were maintained in the same environment prior to and during the testing which approximated the environment conditions specified for the test, $70^{o}F \pm 3^{o}F$ and 30% ± 3% RH.

2.4.2 Results

The Ampex type 797 sample had been employed previously for an abrasivity test, and a crease was present along one edge of that tape. The test was repeated on a new, 1/4 inch sample of Ampex type 797, and identical results were obtained. The Ampex type 466 sample was a one inch tape width rather than the 1/2 inch width specified for the test.

2.4.3 Conclusion

The measured angles are listed in the fourth column of Table 1. The thin mylar of Fuji Beridox is very flexible and subjective observation of 3M Type 5198 indicates acceptable flexiblility. All of the measured angles exceed the 30^{o} minimum acceptable angle specified by the IITRI guide lines.

2.5 Lubricant Content

This test measures the weight of lubricants and other low molecular weight compounds which are extractable by a solvent as a percentage of oxide binder system weight. Lubricant is added to the oxide binder system to reduce friction, but excessive lubricant may weaken the integrity of the binder polymer. Benzene is the usual extraction solvent for this test but the possible use of fluorocarbon lubricants suggested the use of

Table 2: Oxide Surface Physical Propertie

Tape Manufacturer and Type (Lot) / Test	Lubricant Content (% weight of oxide binder system) Benzene Extraction	Freon TF Extraction	Elemen (Normalized Absolute Counts Electron Probe Silicon	Fluorine	Oxygen	Carbon
Ampex 466 (5166041921)	1.80*	1.79	0.66 0.57	0.68 0.59	0.85 0.73	0.73 0.88
Ampex 721 (110024182)	1.15	1.47	0.75 0.75	0.73 0.73	1.00 1.00	0.50 0.71
Ampex 797 (76142,16 4485221-4, Lot A-1)	0.62	0.83	0.47 0.33	0.54 0.39	0.79 0.56	1.00 1.00
Fuji Beridox (PFD 018)	0.81	0.69	0.33 0.28	0.68 0.58	0.76 0.65	0.77 0.94
3M 5198 (51575-1-01-58)	0.74	-0.68	1.00 1.00	1.00 1.00	0.93 0.93	0.53 0.74

* Only one sample subjected to benzene extraction

(Table 2 is continued on next page.)

2: Oxide Surface Physical Properties

Elemental Surface Analysis (Normalized Absolute Counts/Normalized Proportions of Total Counts)										
Electron Probe				Oxygen Ion Probe				Oxygen Ion Probe		
Silicon	Fluorine	Oxygen	Carbon	Chlorine	Fluorine	CN	Carbon	Iron	Cobalt	Carbon
0.66	0.68	0.85	0.73	0.17	0.57	0.20	0.76	0.67	0.21	0.87
0.57	0.59	0.73	0.88	0.30	0.76	0.35	0.87	0.90	0.35	0.53
0.75	0.73	1.00	0.50	0.09	0.61	0.22	0.57	1.00	0.20	0.84
0.75	0.73	1.00	0.71	0.19	1.00	0.46	0.79	1.00	0.25	0.39
0.47	0.54	0.79	1.00	0.05	0.48	0.11	1.00	0.33	0.00	0.79
0.33	0.39	0.56	1.00	0.07	0.57	0.16	1.00	0.91	0.00	1.00
0.33	0.68	0.76	0.77	--	--	--	--	--	--	--
0.28	0.58	0.65	0.94							
1.00	1.00	0.93	0.53	1.00	1.00	1.00	0.61	0.78	1.00	1.00
1.00	1.00	0.93	0.74	1.00	0.79	1.00	0.89	0.63	1.00	0.37

2 FOLDOUT FRAME

Table 2 (Continued): Oxide Surface Physical Properties

Tape Manufacturer and Type (Lot) / Test	Coefficients of Friction				Abrasivity (Head Wear)		
	μs (static)		μd (dynamic)		Width (mils)		Width (normalized)
	Mean	σ	Mean	σ	Mean	σ	
Ampex 466 (5166041921)	--	--	--	--	--	--	--
Ampex 721 (11Q024182) (11Q024171)*	0.327	0.014	0.287	0.010	22.1	2.4	1.00
Ampex 797 (76142,16 4485221-4, Lot A-1) (" , 164485 222-33,")*	0.351	0.030	0.283	0.022	9.3	1.2	0.42
Fuji Beridox (PFD 018)	--	--	--	--	--	--	--
3M 5198 (51575-1-01-58) (51575-1-01-15)*	0.457	0.018	0.330	0.018	22.2	3.8	1.00

* Lot of second abrasivity test sample

Freon TF as the extraction solvent.

2.5.1 Procedure

Obtain virgin samples of each tape under consideration. The samples must not be contaminated with body oils, lint or dirt. Tweezers, petri dishes, and work surfaces covered with clean polyester sheets are required to facilitate sample handling and preparation.

All samples should be 18 square inches ±1%. Two tape strips 0.248 ±0.002 inches wide and 36 ±0.03 inches long provide this area tolerance. Five samples were employed for oxide binder system and benzene extracted lubricant weights in the current experimental series. Single samples were employed for Freon TF extractions, with the exception of 3M Type 5198, where two samples gained identical weight following Feon TF treatment. The results indicate that single samples are acceptable for oxide binder system weights but that a mean derived from five or more lubricant sample weights is desireable.

Label and weigh each tape sample prior to treatments. An analytical balance with 10 microgram resolution is suitable. Divide the preweighed samples into groups for oxide binder system removal and lubricant extractions.

Remove the oxide binder system with methyl ethyl ketone (MEK) and cotton swabs or lint free wipers (Kim Wipes). Note that contact of the MEK and the back coating is unavoidable. However, if the tape is placed oxide up on a polyester sheet and stroked lightly with an MEK saturated wiper, the back coating will adhere firmly to the polyester sheet before it is loosened significantly. The adhesion will prevent mechanical disruption of the MEK wetted back coating and will minimize addition of dissolved oxide binder to the back coating. Note the ease of oxide removal with MEK as a subjective indication of the oxide binder system strength (Section 2.2).

Extract the lubricant from the other groups of samples by soaking for at least 12 hours in selected solvents. Stand the tape on edge in petri dishes during benzene treatment to facilitate complete wetting. Freon treated samples may be soaked in loosely capped polyproplyene bottles. The oxide binder system and back coating should remain intact during extraction and subsequent sample drying.

Dry thoroughly, and reweigh all samples. Calculate the mean weight losses following treatment for each group. Calculate the lubricant weight as a percent of the oxide binder system weight:

$$\frac{\text{Lubricant weight}}{\text{Binder weight}} \times 100\% = \%\ \text{Lubricant Content}$$

2.5.2 Results

The lubricant contents of the subject tape are listed in the first column of Table 2. Standard deviations of the oxide binder system weights were less than or equal to 0.5% of the weights, while standard deviations of the benzene extracted lubricant weights ranged from 5% to 19% of the weights. The lubricant weight variability may be due to experimental error such as contamination of a sample by a single dust particle or incomplete wetting of the samples. One benzene treated 3M Type 5198 sample was deleted from the calculations due to a very low lubricant weight and a visable residue on the tape surface after drying which suggested incomplete wetting. The Freon TF treated samples were resoaked for an additional 72 hours following the initial post treatment weighing. The 3M Type 5198 sample continued to gain weight during this treatment while weights of other samples did not change significantly.

2.5.3 Conclusions

Lubricant weights of the tapes are within or close to IITRI guidelines which recommend a 1% lower limit and a 2% upper limit. That conclusion ignores the 3M Type 5198 Freon TF treatment results which are obviously due to phenomena other than extraction of lubricants. Analysis of that result and lubricant type identification are in progress. Preliminary data for the analysis are included in the next section.

2.6 Elemental Surface Analysis

Detection and measurement of elements present near the oxide coating surface of magnetic tapes provides indications of the types and relative amounts of metal oxides, binders, and lubricants on the tape surfaces. Two methods, electron probe and ion probe, have been employed for elemental analysis. Both methods direct beams of high energy charged particles onto the surface of the tapes which induce the emission of small ions from materials of the oxide surface. The sample size and depth can be controlled by the focus, energy, intensity and duration of the particle beam.

The ions released from the tape surface by the probe beams are directed to a mass spetrometer which separates, detects, and counts the individual atoms or polyatomic ions released from the tape surface.

Of the two methods, the electron probe is considered simpler and more repeatable, but it is less sensitive, especially with respect to heavier elements, than the ion probe. Neither method measures the absolute quantitative amount of elements on a sample surface because some elements are ionized more efficiently than others by the probe beams.

2.6.1 Procedure

Virgin tape samples obtained for each type without body contact were placed in polyethylene bags and were submitted for analysis. Beam parameters were selected for a penatration depth of 8 microinches (2000 angstroms). Actual beam parameters will be specified in later reports, and methods of measuring the actual beam penetration will be considered.

An electron beam analysis was performed on each tape type. Two oxygen ion probe analyses were perforemd on each tape type except Fuji Beridox, one for measuring light elements and a second tailored to iron and cobalt.

In addition to virgin oxide surface analysis, elemental surface analysis of back coatings and oxide surfaces subjected to lubricant extractions were performed. These tests may provide background counts of trace elements and information regarding the types and amounts of material removed during lubricant content extractions (Section 2.4).

2.6.2 Results

Columns 2, 3, and 4 of Table 2 list normalized counts for typical elements identified in the subject tapes. Two values are listed for each tape and each element. The top number is the normalized absolute number of counts for the element of that column. Since the total number of counts varied for each tape during a given analysis method, the proportional number of counts for each element in a given tape were calculated. The bottom numbers in columns 2, 3 and 4 of Table 2 list the normalized proportional number of counts for the elements in those columns. Therefore, the bottom figures may more accurately reflect the relative proportions of counts in the tapes.

A second method of treating the raw data is under consideration. The raw counts could be multiplied by the atomic weights of the elements and the results could be normalized in the same manner as the raw counts were normalized for Table 2. This data reduction method may more accurately reflect the differences between elements present on tape surfaces by weight rather than by numbers of atoms.

Recall that the elements detected during the analysis may be released from the tape surfaces by the impinging particle beam with differences in efficiency, and that these efficiency rates may even vary from tape type to type. Therefore, vertical comparisons of differences in amounts of elements between tape types must be considered with caution. Horizontal comparisons of amounts of elements in a given tape are not indicated by the values in Table 2. However, examination of the raw counts does suggest that elements

are detected in proportion to the magnitudes of their expected proportions in the tapes. For example carbon, oxygen and CN produce large numbers of counts as might be expected from their likely presence in the binder polymer, lubricants, and metal oxides located close to the tape surface. Silicon, fluorine, chlorine and cobalt were detected in lower proportions as might be expected from their presence in lubricants alone, as oxide dopants, or as trace elements. One exception is 3M Type 5198 where more cobalt was detected than iron.

Ion probe results from Fuji Beridox were not yet available when this report was prepared.

2.6.3 Conclusions

As discussed above, comparisons of the subject tapes based on the elemental surface analysis is difficult because the counts may not correspond to the quantitative amounts of elements in the tapes. However, some tentative indications and conclusions can be drawn from vertical comparisons of the results of Table 2, absolute numbers of counts, and other test results.

Silicon and fluorine were detected in all tapes and in equal orders of magnitude, and their relative abundances do not correlate with the lubricant content test results. Interestingly, preliminary examination of surface analysis from tape samples subjected to benzene and Freon TF extractions do not show large drops of these elements, although they were expected to be the best indicators of silicone and fluorocarbon lubricants in the tapes. It is possible that some lubricant is evaporating from the tape surfaces in the high vacuum of the analysis instrumentation. The results do not suggest which type of lubricant is employed in the tapes unless both silicone and fluorocarbon lubricants are employed in the same tape types..

The sources of chlorine in the subject tapes were not determined. Its presence in some forms or the possible formation of decomposition products could accelerate degradation of either the head surface or the binder polymer. Therefore, investigation of the absolute concentrations and sources of this element are under consideration. The 3M Type 5198 sample appears to have much more chlorine than other tape types, and the raw counts exceeded 1% of the total counts in that tape type.

The presence of cobalt in Ampex Types 466 and 721, and in 3M Type 5198 correlates with the high coercivities of these tapes as compared to Ampex Type 797 which appears to have pure iron oxide. The 3M Type 5198 sample had a high proportion of cobalt.

The results suggest that the low oxide resistivity of Ampex Type 797 may be accomplished with a moderate increase of surface carbon. Fuji Beridox has the next highest oxide resistivity and the next lowest carbon content, while the three tapes with very high oxide resistivities have the lowest carbon contents.

The detection of cyanide (CN) may be the product of polyurethane binder polymers. If so, the 3M Type 5198 sample may have a higher proportion of polymer than magnetic oxide, at least at the tape surface. The low proportion of CN in Ampex Type 797 and the high proportion of CN in 3M Type 5198 may reflect differences in the proportions of binder polymer which could lead to a difference in oxide binder system strength. That hypothesis correlates with the abrasion resistance of those tape types.

The method of presenting surface analysis data requires additional consideration. The next report will probably indicate actual proportions of elements by counts and weight as well as normalized proportions of elements by counts and weight in an effort to draw more correlations with

other tests. A weight factor based on typical proportions of silicon, fluorine, oxygen and carbon in silicone and fluorocarbon lubricants may also be beneficial in ranking relative abundances of tape surface materials. However, the results cannot be treated as actual concentrations of elements in the tape surfaces.

2.7 Coefficient of Friction

This test measures the coefficient of friction between the tape oxide binder system and the tape head. The symbol μs represents the coefficient for the static case when there is no relative motion between the tape and the head, while μd represents the dynamic case when the tape moves across the head. The coefficients are dimensionless ratios which increase as the friction between the tape and the head increases.

2.7.1 Procedure

A Video Research Corporation Model 9209 Tape Tester was adjusted for a 15^{o} total wrap angle. The take up tension was measured in both directions immediately after tape direction changes with a Tentel Model T2-H20-2 Tape Tension Meter and was assumed constant for all friction measurements on a given tape type. Measurements on Ampex Types 721 and 797 obtained during the previous reporting period were made with a 9.5 ounce take up tension. We reduced the tension during the 3M Type 5198 test to a level more suitable for this 1/4 inch tape and found that the tester transport would not function acceptably with a tension less than 6 ounces.

The frictional drag associated with the tape movement across the head was measured with a calibrated strain gauge and amplifier. The output of the strain gauge amplifier was monitored on an oscilloscope, and direction changes on the oscilloscope were photographed. A direction change appears as a horizontal trace due to the dynamic drag of the initial tape direction, a peak corresponding to the static drag immediately after the direction change, and

another horizontal trace corresponding to the dynamic drag after the direction change.

The standard equation for "belt friction" is:

$$\mu = \frac{1}{\beta} \ln \left(\frac{T2}{T1}\right)$$

where μ is the coefficient of friction, β is the total wrap angle, $T2$ is the take up tension, and $T1$ is the supply tension. For small total wrap angles, the dynamic friction force F_d of the tape across the head is approximately the difference between the take up and supply tensions:

$$F_d = T2 - T1$$
$$\text{or } T1 = T2 - F_d$$

The drag force corresponded to the difference between the horizontal portions of the photographed curves is twice the dynamic friction force $F_d = D/2$. Substitution into the standard equation yields

$$\mu d = \frac{1}{\beta} \ln \left(\frac{T2}{T2 - D/2}\right)$$

for the calculation of the dynamic coefficient of friction.

For the static case, the difference between the peak and the dynamic level after the direction change may be doubled and added to the difference between the horizontal portions to obtain twice the static friction force. This value can be entered directly into the equation above for the calculation of the static coefficient of friction.

All photograph measurements are taken at the edges of the traces in the direction of the static peak. Each tape is tested five times, coefficients of friction are calculated for each trial, and means and standard deviation are calculated from the results of the five trials for each tape type.

2.7.2 Discussion

Wide traces at the static peaks of the photographs suggest the possibility of overshoot followed by about 100 ms of ringing in response to a step function (the tape direction change), rather than a real force associated with static friction. It is possible that a stick slip phenomena is respobsible for the wide traces after direction changes, but stick slip would be expected to produce peaks in both directions of tape movement during a direction change which is not apparent on the photographs. These considerations cast some doubt on the validity of the static friction measurements. Figures 1 and 2 are examples of the results for the current reporting period. Figure 1 is a reverse to forward direction change while Figure 2 is a forward to reverse direction change. The shape of the static peaks appears to depend less on the direction change than it did during previous tests.

Trace width and stability appear to be unchanged from the last reporting period, but the capstan motors were replaced, and a real improvement is masked by the reduced drag force associated with the reduced tension and the increased sensitivity of the recording oscilloscope.

We plan to employ the current tension setting for all future tests of 1/4 inch and 1/2 inch tapes, to improve the take up tension measurement accuracy by recording drag and tension simultaneously, and to revise the coefficient of friction measurements in future reports. Tape width will also be standardized if suitable samples can be obtained.

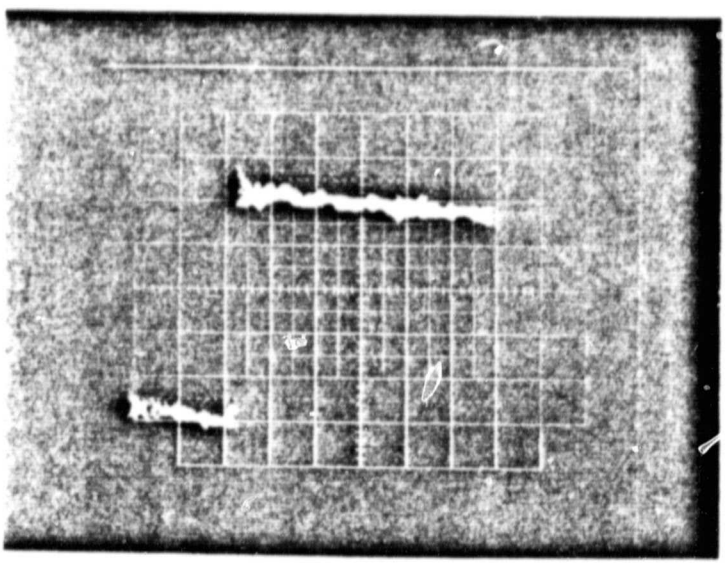


Figure 1: Drag force during reverse to forward direction change of 3M Type 5198. Vertical Scale: 0.22 oz./div.

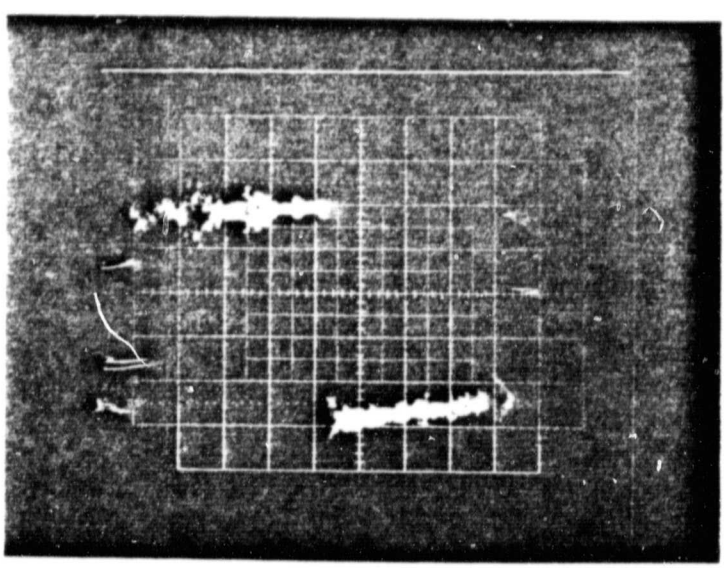


Figure 2: Drag force during forward to reverse direction change of 3M Type 5198. Vertical Scale: 0.22 oz./div.

2.7.3 Results

The previous results for Ampex Types 721 and 797 are listed in the fifth column of Table 2 along with the results for 3M Type 5198 obtained with the reduced tape width and tension setting mentioned above. Due to likely sources of error and possible effects of different tension settings, no conclusions should be drawn from the results until a set of standardized test can be conducted.

2.8 Abrasivity

This test measures the relative degree of head wear produced by different tape types. The test method and the scale of results should not be considered a linear indicator of relative head wear. Nonlinear effects and methods of correcting them are under consideration.

2.8.1 Procedure

This currently reported test series was conducted twice on each available 1/4 inch wide tape type at ambient temperatures of 75 $\pm$ 5 ^{o}F and relative humidities of 14% to 21%. Samples were obtained from different tape reels. The following procedure was employed for each tape type, and the means and standard deviations derived from six wear width measurements were calculated for each type.

Wind 1700 feet of virgin tape onto a supply reel. Mount a clean alfesil test bar with an unworn edge on the test fixture. Install the test fixture on the tape transport. The test fixture provides a 16^{o} total wrap angle with 8^{o} of wrap on each side of the bar. Set the transport tape speed to 3-3/4 ips and the tape tension to 16 ounces/inch of tape width. Run the test tape end to end for one pass only. Define the reference end of the wear pattern as the end toward lower track numbers of a tape recorder head. For recorders with supply reels that turn counterclockwise for the forward tape direction, the reference end of the wear

pattern is the end closest to the tape recorder. Remove the test bar and mount on a microscope with a calibrated scale and 400 x optics. Measure the width of the wear at three points: one fourth, one half, and three forths of the distance from the reference end to the opposite end of the wear pattern by sharply focusing the edges of the wear pattern, observing the width against the microscope scale, and multiplying the divisions by the microscope scale calibration factor. During microscopic observation, unusual wear patterns such as scalloping of the worn surface or flaking of the worn bar edge should be noted and recorded.

2.8.2 Results

The last column of Table 2 lists the results of the test series conducted at the environmental conditions specified above and with standardized tape width and tension.

2.8.3 Conclusions

The current test results suggest that abrasivity increases with abrasion resistance and binder strength results in Table 1. No other likely correlations were obvious from the data obtained up to this point.

Nonstandardized test conditions cast doubt on the validity of previous results, and those results have not been included in this report.

3. MAGNETIC PROPERTIES

This section includes the results of a series of longitudinal B-H measurements and derived parameters from the subject tape types. Serious phase, noise, linearity, and maximum applied field problems which prevented acceptable measurements prior to this report have been overcome, but we plan additional checks of the remanance (B) axis calibration prior to multiple and transverse sample testing. The following discussion mentions important test conditions, sample selection, instrument calibration methods, and unusual test results. Conclusions have been witheld pending additional calibration checks and test series.

The field and sensing coils of the IITRI B-H curve plotter appear readily adaptable to the new tape evaluation facility environmental chamber. Current plans include transverse measurements to obtain orientation ratios and magnetic testing with environmental variations. Initial results of environmental variation measurements can be expected in the next report. Future reports will also include a formalized procedure for sample preperation, B-H curve plotter calibration and operation, and data reduction.

In addition, a more precise Switching Field Distribution measurement method based on expanding the H axis gain will be investigated. The method requires an oscilloscope with gain that can be varied in known increments by switching ranges without readjusting its variable gain controls. This feature is not usually indicated on instrument specifications and must be verified prior to trials of the improved precision method. The method should produce photographs with less steep and more precisely measureable slopes.

3.1 Procedure and Discussion

Table 3 presents results of magnetic property testing on single longitudinally oriented samples of the subject tape types. All testing was conducted on the IITRI Dynamic B-H Curve Plotter with an applied 60 Hz field and H_{max} equal to 2000 oersteds. Multiple sample testing including transverse measurements will be conducted following additional plotter calibration verification indicated below. Virgin tape samples from 1/4 inch reels of Ampex Types 721 and 797, and 3M Type 5198 were obtained 1800 feet into the 4600 feet reels. The Ampex Type 466 and Fuji Beridox samples are from the beginning of a 1 inch reel and the end of a 1/2 inch cassette respectively.

The B-H Curve Plotter calibration was affected by recent repairs, and magnetic material standards available at IITRI were found to be unsuitable for recalibration of the plotter. The plotter field strength was verified with a Radio Frequency Laboratories Model 1295A Gaussmeter and a traceable calibration magnet. The coercivity value H_c obtained for Ampex Type 721 with this known applied field corresponds to the manufacturer's published centerline specification. The remanance axis of the B-H Curve Plotter was then calibrated with the published centerline specification of 1000 gauss for the retentivity B_r of Ampex Type 721 as the standard. Therefore, the tabulated values of retentivity and saturation induction B_m should not be considered absolute at this time. We will obtain samples measured by other laboratories and correlate their remanence axis values with our measurements.

The retentivity and saturation induction values given in Table 2 are suitable for relative comparisons of the subject tapes and the squareness ratios B_r/B_m should not be affected by the lack of absolute calibration. The squareness ratio of Ampex 797 appears to be unusually high. However, general observations and a squareness ratio of 0.63 which we obtained from low orientation floppy disc material indicates that our curve plotter does not have phase or linearity errors which would cause a high squareness ratio for Ampex Type 797.

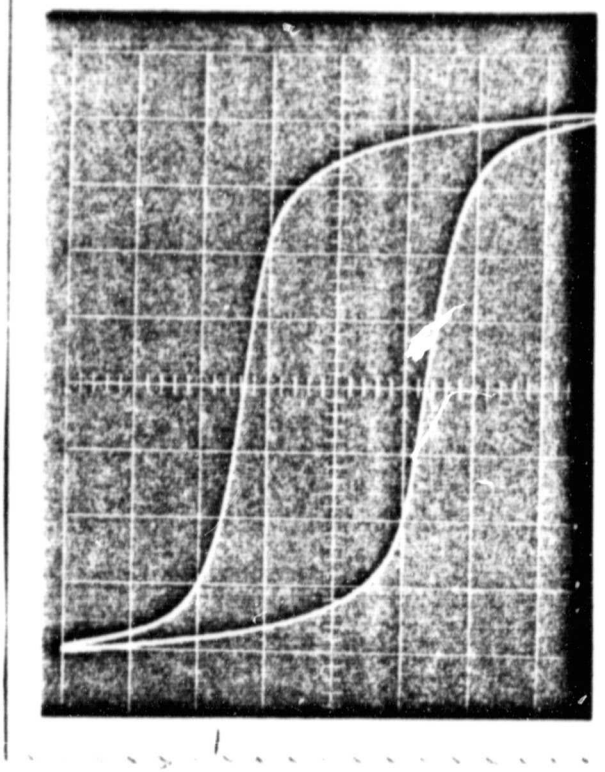
The top photographs of Figures 3.1 through 3.5 are the plotted B-H curves from which B_m, B_r, H_c, and squareness were measured. The horizontal coercive force axis scale is 250 oersteds/division and the vertical remanence axis scale is 125 Gauss/division for all tape types except Ampex 721 which has a remanence scale of 250 gauss/division.

The values for switching field distribution (SFD) were measured from hand plotted curves shown on the bottom of Figures 3.1 through 3.5 of the derivative of remanence with respect to coercive force (dB/dH). These values are the width of the derivative curves in oersted at the half amplitude level. The dB/dH curves were produced by selecting values in divisions along one axis and measuring corresponding values in divisions along the other axis from which we obtained tables of points along the B-H curves in the second and third quadrants. Remanance increments were increased in direct proportion to the apparent slope of the B-H curves. The slope of the line ($\Delta B/\Delta H$) and the mean applied filed $(H_1 + H_2)/2$ for each pair of adjacent points are then calculated and plotted on linear graph paper. A smooth dB/dH curve is drawn through the plotted points, the half amplitude level is determined and the width of the curve at that level is measured in divisions and multiplied by the horizontal scale factor to obtain the SFD. The precision of this process is limited by the ability to measure the photographs to the nearest 0.05 division and select points which indicate the maximum dB/dH amplitude. The SFD values have been rounded to reflect these precision limitations. We repeated the SFD determination with different points for all tape types and obtained repeatable results for the four types with moderate maximum slopes. The two dB/dH curves of Figure 3.3 for Ampex Type 797 indicate that the SFD calculation is less accurate for a B-H curve with a steep slope. We believe, however, that the percision of the SFD values in this report is adequate to rank the performance of the subject tapes.

The normalized switching field distributions (SFD/H_c) are listed in the last column of Table 3.

Table 3 : Longitudinal Magnetic Properties

Tape Manufacturer and Type (Lot) / Test	Saturation Induction B_m (Gauss)	Residual Induction B_r (Gauss)	Coercivity H_c (Oersteds)	Squareness Ratio B_r/B_m	Switching Field Distribution (SFD) (Oersteds)	Normalized SFD $\frac{SFD}{H_c}$
Ampex 466 (5166041921)	1025	838	663	0.818	140	0.21
Ampex 721 (11Q024182)	1250	1000	650	0.800	100	0.15
Ampex 797 (76142,164485221-4, Lot A-1)	1056	900	325	0.852	40	0.12
Fuji Beridox (PFD 018)	1088	888	650	0.816	140	0.22
3M 5198 (51575-1-01-58)	944	756	650	0.801	180	0.28



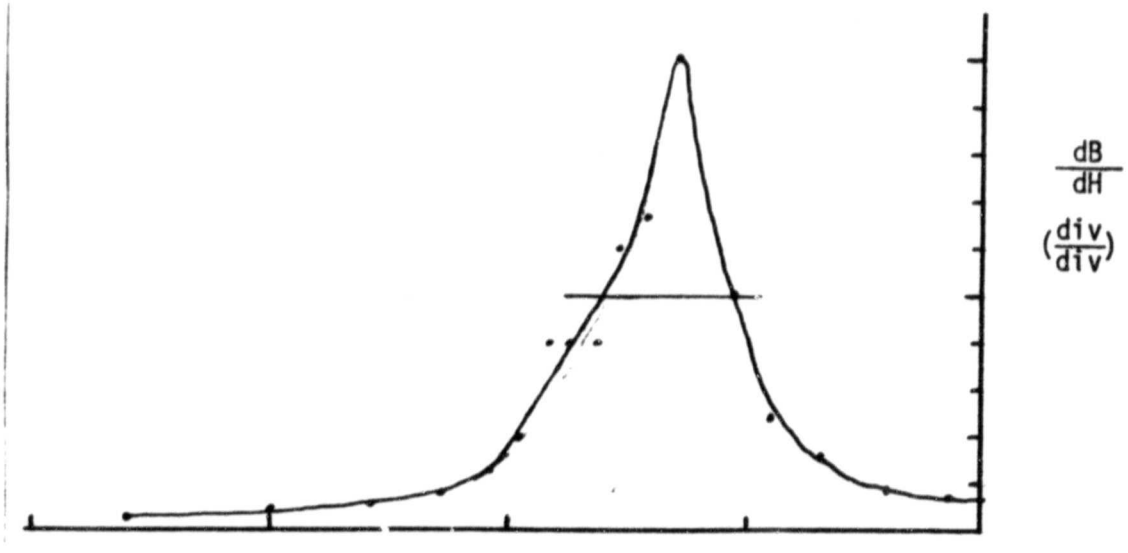
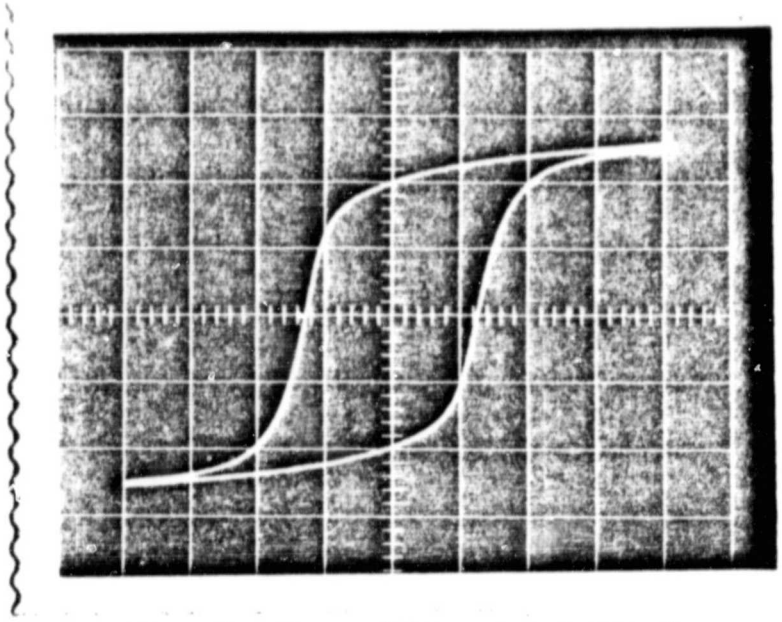
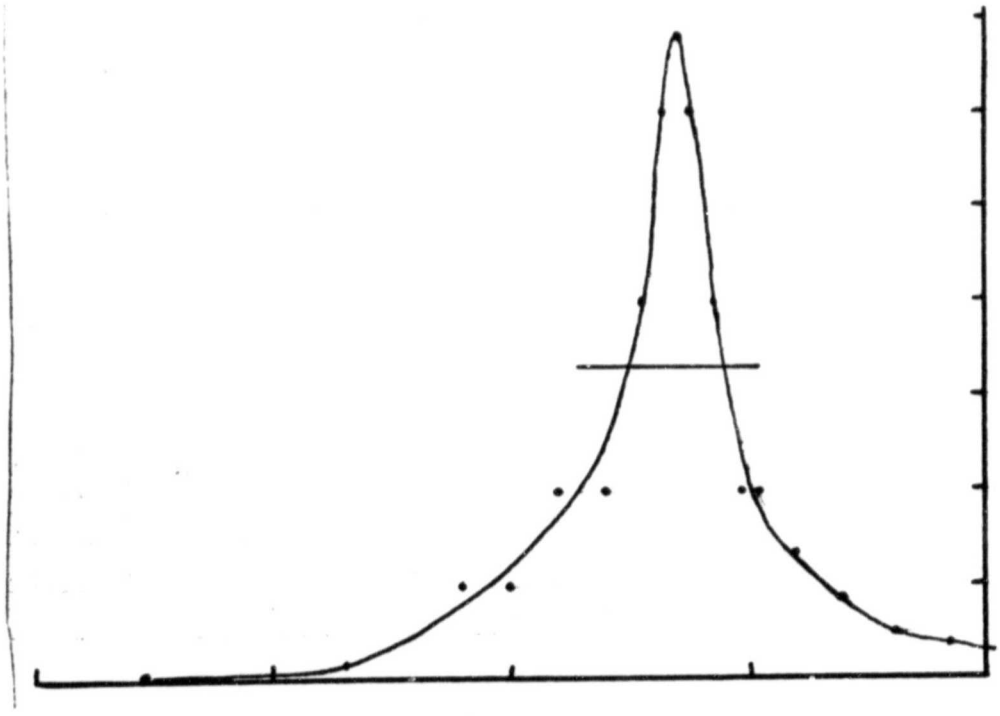


Figure 3.1: Ampex Type 466 longitudinal B-H curve (top) and derivative of B-H curve (bottom) with line across half amplitude level. SFD = 0.55 div. x 250 = 140 Oersteds.



Remanance
(250 $\frac{\text{gauss}}{\text{div.}}$)

Coercive Force (250 oersteds/div.)

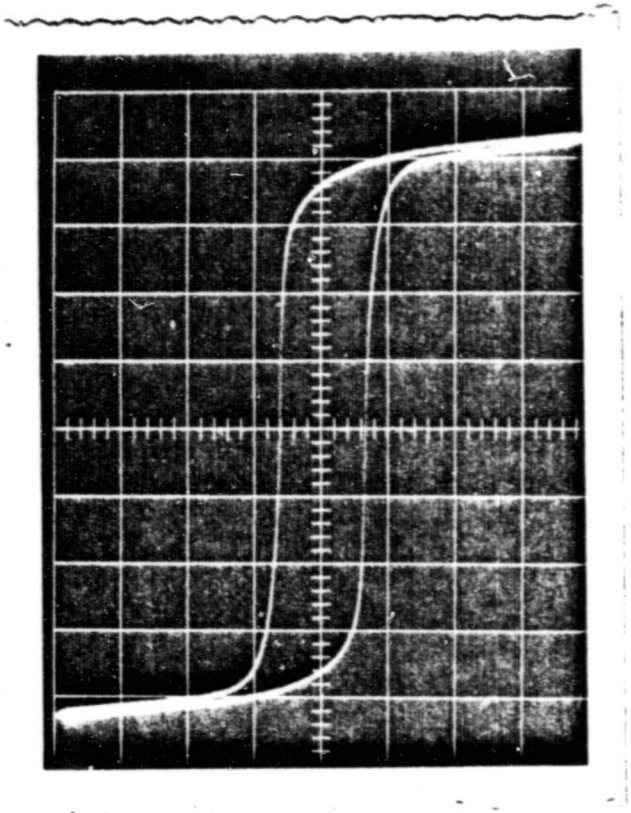


$\frac{dB}{dH}$

$(\frac{\text{div.}}{\text{div.}})$

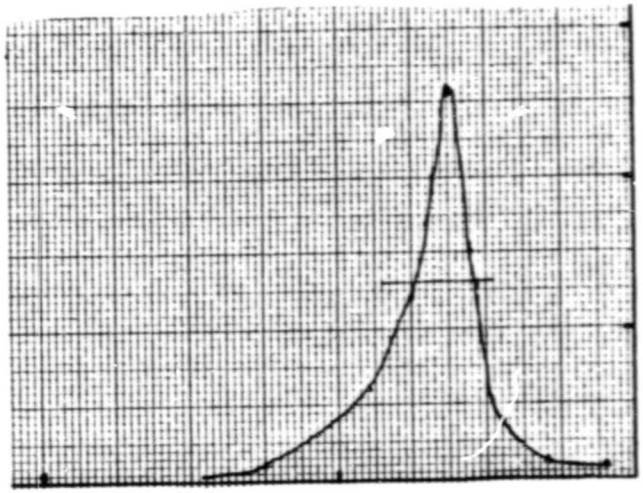
Applied Field (250 oersteds/div.)

Figure 3.2: Ampex Type 721 Longitudinal B-H curve (top) and derivative of B-H curve (bottom) with line across half amplitude level. SFD + 0.4 div. x 250 = 100 oersteds



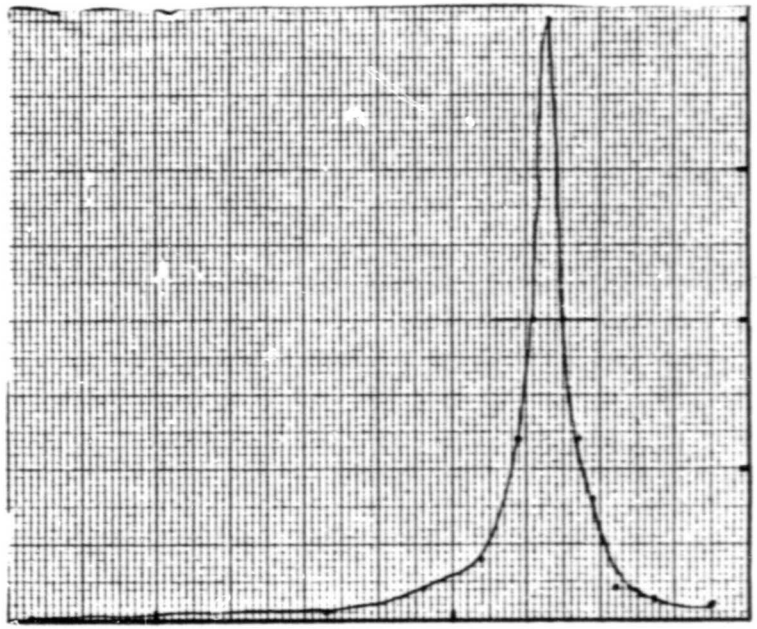
Coercive Force (250 oersteds/div)

Remanance
(125 $\frac{\text{gauss}}{\text{div.}}$)



$\frac{dB}{dH}$

$(\frac{10 \text{ div.}}{\text{div.}})$

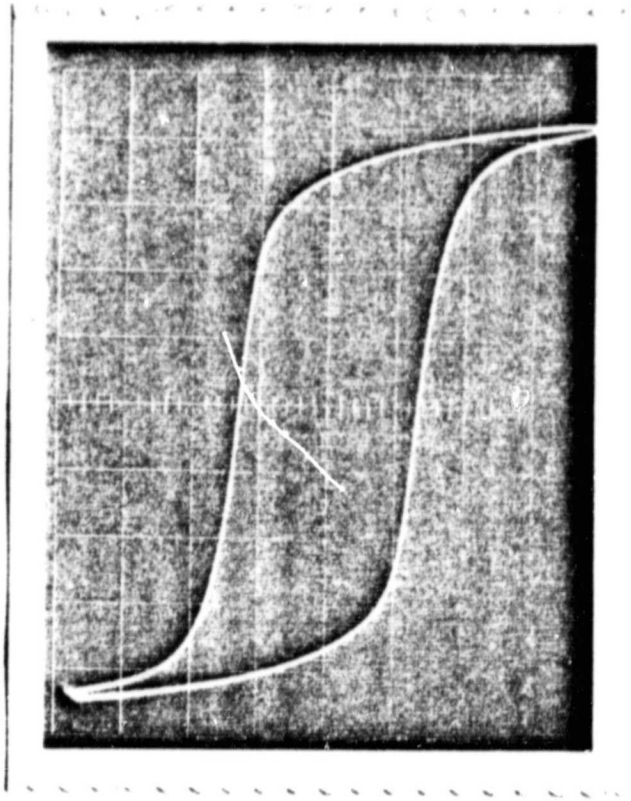


$\frac{dB}{dH}$

$(\frac{10 \text{ div.}}{\text{div.}})$

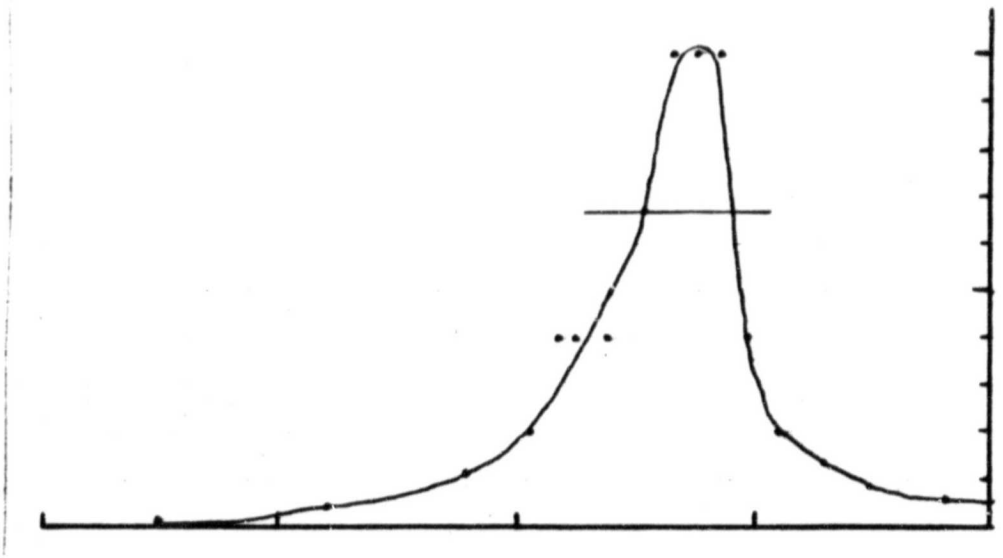
Applied Field (250 oersteds/div.)

Figure 3.3: Ampex Type 797
Longitudinal B-H curve (top)
and derivatives of B-H curve (right)
based on two different measurements of
the same B-H curve.
SFD = 0.18 div x 250 = 45 gauss (top right)
SFD = 0.10 div x 250 = 25 gauss (bottom right)



Remanance
(125 gauss/div.)

Coercive Force (250 oersteds/div.)

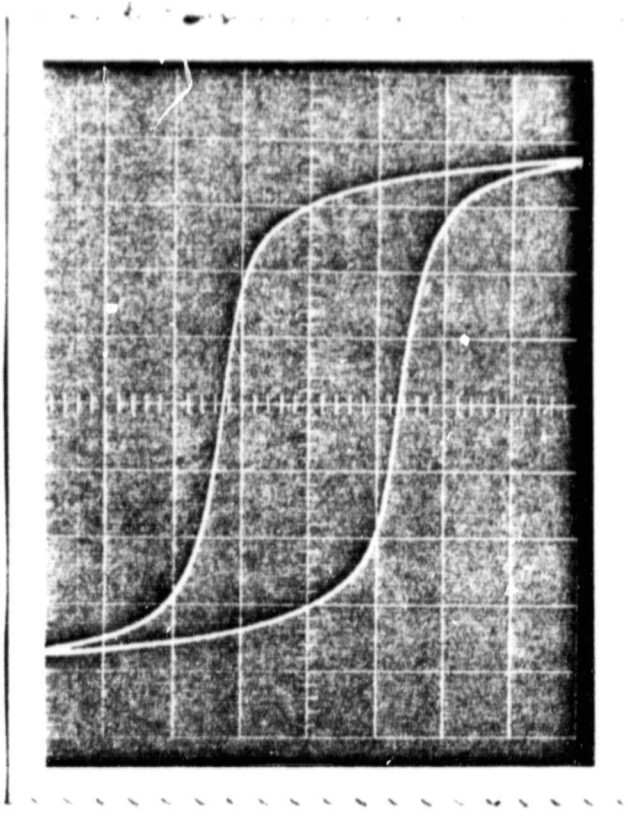


$\frac{dB}{dH}$

$(\frac{div.}{div.})$

Applied Field (250 oersteds/div.)

Figure 3.4: Fuji Beridox Longitudinal B-H curve (top) and derivative of B-H curve (bottom) with line across half amplitude level. SFD = 0.38 div. x 250 = 100 oersteds



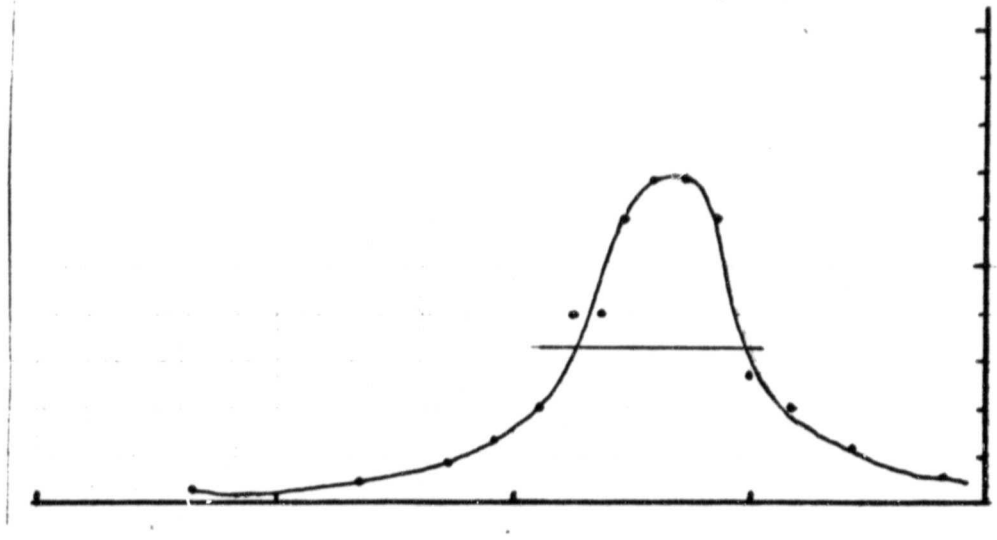


Figure 3.5: 3M Type 5198 Longitudianl B-H Curve (top) and derivative of 3-H curve (bottom) with line across half amplitude point. SFD = 0.70 div x 250 = 180 oersteds

4. MEDIA PERFORMANCE TESTS

This section adds coating resistivity test results for 3M Type 5198 and Fuji Beridox to previously reported results. Additional record current and wavelength response tests were not attempted. We anticipate that record electronics currently in final construction stages will enhance test methodology and standardization.

4.1 Record Current Without Bias

The purpose of this test is to measure the record current at selected wavelengths required to achieve an output signal 5.5 dB below the maxium obtainable output signal level.

4.1.1 Procedure

A sqaure wave output voltage from a Krohn-Hite Model 5200 Function Generator was applied to track 12 of an Ampex 14 track, 1 inch (50 mil) Record Head. The record current was measured with a Tektronix Type P6019 AC Current Probe and an HP 3403C true RMS voltmeter. The signals recorded on the test tapes were reproduced through track 35 on a Honeywell 42 track, 1 inch (17 mil) Reproduce Head, preamplifier, equalizer and 4 MHz Direct Reproduce Amplifier supplied with the Honeywell Model 96HD Tape Recorder. The output voltage of the reproduce amplifier was monitored on a Hewlett Packard Model 3400 True RMS Voltmeter.

For each test tape and frequency, the output of the function generator was increased until the maximum output signal was observed. Then the function generator output was reduced until the recorder amplifier output was 5.5 dB below the maximum observed output level, and the record current was measured.

Each test tape was run at 60 ips. At that speed, frequencies of 2.0 MHz, 1.0 MHz, 0.20 MHz, and 1.0 kHz correspond to wavelengths of 0.030 mils, 0.060 mils, 0.30 mils, and 60 mils respectively.

4.1.2 Results

The results of the record current without bias tests are listed in the first column of Table 4. All of the tapes employed for the tests were new with the exception of Ampex type 797 which had previously been employed for an abrasivity test.

The maximum reproduced outputs of two tapes, Ampex Type 797 and 3M Type 890, were less than 5.5 dB above the background noise levels for shorter wavelengths. For these tape types, we noted minimum wavelengths of 0.032 mils (Ampex Type 797) and 0.187 mils (3M Type 890) which resulted in maximum reproduced outputs 5.5 dB above the noise level.

Excessive white, granular debris accumulated on the heads during the initial attempts to test 3M Type 890. That tape was run through the recorder twice with frequent head cleaning before useful measurements were obtained.

4.2 Wavelength Response

The purpose of this test is to measure the tape recorder reproduce level at selected wavelengths with a constant record current. The record current which produced an output 5.5 dB below the maximum as determined by the record current test at the 0.30 mil wavelength corresponding to 0.1 times the upper band edge frequency (UBE) was employed for a given tape.

4.2.1 Procedure

The test equipment was identical to that employed for the record current test in Section 4.1.1. For each wavelength, the record current was adjusted by varying the output voltage of the function generator until the indicated record current was obtained. Then the reproduce voltage in dB was measured. For each tape, the reproduce voltages were normalized to a reference level of 0.0 dB corresponding to the level at the wavelength with the maximum response for a given tape.

4.2.2 Results

The results of the wavelength response tests are listed in the second column of Table 4. The same tapes, tape speed, and wavelengths were employed for this test and for the record current test.

4.3 Coating Resistivity

4.3.1 Procedure

The coating resistivity of the magnetic oxides and the back coatings of the tape samples were measured with a Hewlett-Packard Model 4329A High Resistance Meter. The test fixture permits five measurements on each sample. The reported oxide results are for 500 VDC test potentials.

4.3.2 Discussion

The coating resistivity test procedure generally followed methods specified in Volume III Appendix B, paragraph 3-61(b) of IRIG 106-80 and the Electronic Industries Association "Recommended Test Method -- Magnetic Tape Electrical Resistance Coating," RS-342 (ANSI C83.36-1968), which differ mainly in the applied test potential: 500 VDC required in the IRIG standard and 100 VDC preferred in the EIA standard. The relationship between resistance and test voltage is probably nonlinear with lower resistance occuring as the test potential is increased. Since low coating resistivity is desireable to prevent the buildup on static electricity, a phenomenon associated with high voltage, the higher test potential appears to be the most rational choice for future tests. However, the higher power dissapation in the tape samples which results from a high test potentials may increase two technical problems in an objective, unbiased evaluation of coating resistivity. First, the test electrodes are secured at each end, and the contact resistance between the tape samples and the electrodes may be less at the tape edges than at the center. Melting of the mylar base at the sample tape edge was

evident following some of the tests. On the other hand, the contact force between the electrodes and the samples did not have a large effect on the measured resistivities. Therefore, this first problem can be reduced by applying nominal torque to the screws that secure the electrodes. We found that "finger tight" screws were adequate. The standards do not specify electrode forces.

The second problem which may be associated with power dissaption in tape samples is the tendancy for the resistance to increase during the application of the test potential, especially with high resistance tape samples. All of the reported measurements were completed within the 2 minute limit specified by the EIA standard, and the resistance values appeared to stabilize within that time period. The resistance change is very rapid upon initial application of the test potential and the initial resistance could not be resolved with the slowly responding test equipment. Our sequential testing of the same sample, first with 100 VDC and then with 500 VDC impedes comparisons of the relative effects of the two test potentials, but lower resistivities were generally obtained during the previous reporting peroid at higher applied potentials. In contrast, to the previous results, the 3M Type 5198 and Fuji Beridox samples produced stable measurements with no significant difference between the results with the two test potentials.

One final procedure problem which was not anticipated in the standards is the possibility of contact between the tape backing and the electrodes if the back to back tape strips are not perfectly aligned on the electrodes. Therefore, some early test results were rejected, and all later tests were conducted with a wide uncoated mylar strip between the two sample strips.

4.3.3 Results and Conclusions

The test results are listed in the third column of Table 2. The Ampex Type 797 coating resistivity is well below the 2×10^8 ohm/square and 1×10^8 ohm/square limits specified by IRIG 118-79 and EIA RS-342 respectively. The oxide coating

resistivities of Ampex Type 721, Ampex Type 466, and 3M Type 5198 were equal to or greater than one hundred times those limits. The oxide resistivity of Fuji Beridox is only three times greater than the $1x10^8$ ohm/square limit. Comparison of coating resitivities with record current and wavelength response tests indicates that the high resistivities may be related to the high frequency capabilities of the tapes. The resistivities of the back coatings of all sample tapes were checked and found to be less than the range of the HP 4329A meter. The Fuji Beridox sample does not have a back coating, but a measured resistivity and large standard deviation on the uncoated side of Fuji Beridox may be due to incidental contact between electrodes and the oxide at the sample edges.

Table 4: Media Performance Tests

Test / Tape Type (Lot)	Record Current Without Bias λ(mil)	Current(mA)	Wavelength Response λ(mil)	Output (dB)	Oxide Electrical Resistance (Ω/square) Mean	S.D.	Back Coating Electrical Resistance Ω/square
Ampex 466 (57GJ11, 51660 41911)	0.030	47.0	0.030	-19.1	3.6×10^{10}	6.6×10^{9}	less than 10^6
	0.060	49.4	0.060	-7.9			
	0.30	65.0	0.30	-4.2			
	60.0	56.4	60.0	0.0			
Ampex 721 (7 593 276GJ11, 21x104061-13)	0.030	45.8	0.030	-21.4	1.7×10^{10}	2.3×10^{9}	less than 10^6
	0.060	49.2	0.060	-10.3			
	0.30	67.4	0.30	-4.7			
	60.0	58.4	60.0	0.0			
Ampex 797 (*)	0.030	**	0.030	-24.7	3.6×10^{6}	4.9×10^{5}	less than 10^6
	0.060	31.7	0.060	-14.4			
	0.30	43.4	0.30	-5.8			
	60.0	38.6	60.0	0.0			
Fuji Beridox (PFD 018)	--	--	--	--	2.9×10^{8}	1.4×10^{7}	no coating mean 1.2×10^{10} σ 9.8×10^{9}
3M 5198 (51575-1-01-58	--	--	--	--	1.8×10^{10}	1.1×10^{8}	less than 10^6

* All tapes new except Ampex 797
** Output at these wavelengths less than 5.5 dB above noise